Remarks

The Rejection of Claims 13, 14, 17-20, and 31 under 35 U.S.C. §102(b)

The Examiner rejected Claims 13, 14, 17-20, and 31 under 35 U.S.C. §102(b) as being anticipated by United States Patent No. 5,537,247 (Xiao).

Applicants have cancelled Claims 13 through 20 and 31 and added new Claims 32 through 46. Since Claims 32 and 46 now contain the key elements of the present invention, Applicants will discuss Claims 32 and 46 in light of the Examiner's above rejection. Applicants respectfully submit that Xiao does not expressly or inherently describe each and every element of the present invention. Specifically, Xiao fails to disclose or teach two elements of Claims 32 and 46: "...means to spectrally fan out an incoming light beam in a detection beam path of said confocal microscope..." and "...means to split said spectrally fanned out light beam out of a dispersion plane for said spectrally fanned out light beam ..."

1) Regarding the first element, a "means to *spectrally fan out* (emphasis added) an incoming light beam in a detection beam path of said confocal microscope..." in Section 2 of the June 3, 2003 final Office Action, the Examiner states: "Xiao discloses an optical arrangement for *spectrally fanning out* (emphasis added) an incoming beam (82) from an object (70) in a detection beam path (84) of a confocal microscope for subsequent splitting by mirrors (42, 43) of the spectrally fanned out beam out of its dispersion plane (50) comprising at least one detector (21,22) for detection of a spectral range of said split spectrally fanned out beam and a pinhole occluder (51) having a rectangular passageway, wherein said incoming beam is *focused* (emphasis added) on said pinhole occluder by lens (34)." Applicants respectfully note that there is no beam (82) in Xiao and assume the Examiner is citing beam path (82). Thus, the Examiner is asserting that Xiao is spectrally fanning the beam upstream of the aperture plate (50), since the Examiner has identified the plate (50) as the dispersion plane for the allegedly fanned beam. Applicants respectfully disagree with the Primary Examiner's description of the Xiao optical arrangement and maintain that Xiao does not disclose the abovementioned element required by Claims 32 and 46.

Spectral fanning, or optical dispersion, of a light beam can be accomplished by a prism or a diffraction grating. In the case of the present invention, Figures 1 through 5 show the use of a prism (10). Therefore, it is necessary for Xiao to include a dispersion element, such as a prism or diffraction grating, in the detection path, particularly between object (70) and plate (50), in accordance with Section 2 of the June 3, 2003 final Office Action. However, Applicants can find no disclosure of a prism or diffraction grating anywhere in Xiao, as is further detailed below. Xiao uses lens, beam splitters, apertures, and mirrors, none of which are typically known as dispersion devices in the art. In fact, for lens, dispersion causes chromatic aberration, an undesirable effect that degrades image quality. Thus, efforts are made to eliminate, rather than emphasize dispersion in a lens.

Referring to FIG. 2 in Xiao, Applicants now examine each element between object (70) and plate (50). From object (70), the light beam on path (83) passes through objective lens (34) and scan lens (33). The functions of objective and scan lens in a confocal microscope are well known and do not include spectral fanning (dispersion) of a detection beam. The function of lens (34) is further illustrated by the above referenced Section 2, in which the Examiner asserts that lens (34) is used to focus, rather than disperse, a light beam. The scanner 60 redirects (reflects) light to the reflecting mirror (40). Xiao does not disclose that scanner (60) or mirror (40) is used to spectrally fan the detection beam. Collimating lens (31) between the scanner (60) and the mirror (40) creates a structured beam of light having <u>parallel</u> light waves; therefore, lens (31) does not spectrally fan the detection beam. Thus, no element of Xiao between the object (70) and the plate (50) is disclosed as a means to spectrally fan the detection beam.

From the reflecting mirror (40) the light beam passes through aperture (51) and beam splitter (41). Although the Examiner asserts that plate (50) is the dispersion plane for a spectrally fanned out beam, we can examine the plate (50) and beam splitter (41), the two remaining elements upstream of the mirrors (42,43), to determine a hypothetical ability of these elements to disperse the beam. Apertures in confocal microscopes are typically used to filter unfocused light and, in the present invention, are used to create specific diffraction patterns. Applicants can find no disclosure in Xiao that plate (50) is a spectral fanning means.

Beam splitters, or dichroic mirrors, reflect light shorter than a specified wavelength and pass light longer than the specified wavelength. Thus, dichroic mirrors are used to filter or redirect a light beam and do not disperse or spectrally fan a light beam. That is, the light passed or reflected by a dichroic mirror is still "mixed," rather than separated by wavelength. The present invention spectral fanning means spatially separates the component wavelengths of light in beam (2). That is, wavelengths of light in beam (2) occupy respective discrete locations in beam (2) and dispersion plane (3). In contrast, the wavelengths of light making up a beam either passing through or being reflected by mirrors (42,43) are not spatially separated, as is the case for beam (2) of the present invention.

In the abovementioned Section 2, the Examiner also cites a number of excerpts from Xiao, to support the rejection of Claims 13 and 32. Applicants respectfully submits that the elements described in these excerpts only perform the respective functions typically associated with lens, beam splitters, and mirrors in a confocal microscope. Such functions do not include spectrally fanning a light beam.

FIGS. 3, 5, and 6 also were cited in Section 2 of the June 3, 2003 final Office Action. FIG. 3 shows details of aperture plate (50) and does not disclose the aperture plate as a device to spectrally fan a light beam. FIG. 5 addresses a tilt angle for plate (50) and does not disclose the aperture plate as a device to spectrally fan a light beam. FIG. 6 describes elements downstream of mirror (41), and therefore, in accordance with the Examiner's assertion in Section 2, does not address the spectral fanning of the light beam.

Therefore, Xiao does not disclose "...means to spectrally fan out an incoming light beam in a detection beam path of said confocal microscope..." and does not anticipate Claim 32 or Claim 46 under 35 U.S.C. §102. Claims 33 through 45, dependent from Claim 32, enjoy the same distinction. The Applicants request that the rejection be withdrawn.

2) Regarding "...means to split said spectrally fanned out light beam out of a dispersion plane for said spectrally fanned out light beam ..." in Section 2 of the June 3, 2003 final Office Action, the Examiner states that: "Xiao discloses an optical arrangement for...subsequent splitting by *mirrors (42, 43)* (emphasis added) of the spectrally fanned out beam out of its

dispersion plane (50)…" Thus, the Examiner is citing dichroic mirrors (42 and 43) as the optical arrangement for splitting a spectrally fanned out beam. Applicants respectfully submit that Xiao does not disclose the present invention splitting means. Mirrors (42,43) are nothing like the splitting means illustrated by gap/detection arrangement (12) in Fig. 3 of the present invention. Dichroic mirrors pass or reflect a light beam according to the wavelength of the light beam and typically are insensitive to where a light beam strikes the mirror. For example, a dichroic mirror designed to pass a certain wavelength of light will pass that wavelength regardless of where the light strikes the mirror. However, the present invention works on a dramatically different principle. As illustrated in Fig. 3 of the present invention, the location of the spectrally fanned out light beam on a detection gap element (gap [6] in Fig. 3), or in general terms, the location of the beam on the splitting means, determines how the beam is split. Thus, the splitting is a spatial function, not a direct function of wavelength. For example, any wavelength of light arriving at the opening in gap (6) is passed on to the detector (5) at the top of Fig. 3. Similarly, any wavelength of light arriving at the reflective portion of the gap (6) is reflected to the detector (5) to the left of the gap/detector arrangement (12). Thus, the present invention teaches using positional coordinates to split a light beam, whereas the Xiao invention can only use the wavelength dependent characteristics of a dichroic mirror to split a hypothetical spectrally fanned out light beam.

Therefore, Xiao does not anticipate Claim 32 or Claim 46 under 35 U.S.C. §102. Claims 33 through 45, dependent from Claim 32, enjoy the same distinction. The Applicants request that the rejection be withdrawn.

Claim 46 further recites "…at least one detector operatively arranged to detect a range of said spectrally fanned out beam on a detection line in said dispersion plane, said detection line defined by diffraction minima of said fanned out beam on said dispersion plane…" Referring to Figs. 1 and 2 of the present invention, passageway (8) produces a single diffraction pattern (13) from the beam (1). However, the multiplicity of diffraction patterns (13) on the dispersion plane (3) is due to prism (10) spectrally fanning beam (1). That is, each pattern (13) in Figs. 1 and 2 is associated with a discrete, or "fanned out" wavelength or group of wavelengths in beam (2). As

shown above, Xiao does not spectrally fan the detection light beam. Hence, in each of Figs. 1 and 2, Xiao would only produce a single diffraction pattern (13) and therefore, could not produce the multiplicity of diffraction patterns (13) on plane (3) and the subsequent detection line (17) required by Claim 32.

Alternately stated, a detection line is only possible if wavelengths to be detected are arranged with respect to spatial coordinates, for example, spectrally fanned out as is done in the present invention. Therefore, Xiao does not anticipate Claim 46 under 35 U.S.C. §102. The Applicants request that the rejection be withdrawn.

The Rejection of Claims 15 and 16 under 35 U.S.C. §103(a)

The Examiner rejected Claims 15 and 16 as being non-obvious under 35 U.S.C. §103(a) over United States Patent No. 5,537,247 (Xiao) in view of applicant's admission that a triangular passageway is an obvious variant of a rectangular passageway or in view of United States Patent No. 5,973,316 (Ebbesen *et al.*).

New Claims 40 and 43 recite a triangular configuration for a passageway, as did cancelled Claims 15 and 16 and, therefore, Applicants direct the discussion to Claims 40 and 43. Since Claims 40 and 43 depend from Claim 32, Applicants respectfully submit that Claims 40 and 43 cannot be found non-obvious in light of the cited references unless Claim 32 is found non-obvious in light of the cited references. With respect to the third *prima facie* requirement to support an obviousness rejection, the combination of the references does not include all the limitations of the claimed invention.

As shown above, Xiao does not disclose or teach "...means to spectrally fan out an incoming light beam in a detection beam path of said confocal microscope..." or "...means to split said spectrally fanned out light beam out of a dispersion plane for said spectrally fanned out light beam ..." as is required for Claim 32.

Applicant's admission that a triangular passageway is an obvious variant of a rectangular passageway does not address the abovementioned elements of Claim 32.

Ebbesen *et al.* generally addresses the problems of filtering light of a predetermined wavelength, collecting light over a distance, improving near-field microscopy, and light transmission in photolithography masks. Ebbesen *et al.* does not address the abovementioned elements of Claim 32. Thus, neither Xiao alone nor Xiao in combination with Applicant's admission that a triangular passageway is an obvious variant of a rectangular passageway or *Ebbesen et al.* arrive at **all** the limitations of Claim 32.

Further, the Examiner has still not demonstrated that the modification of the cited prior art reference points to the reasonable expectation of success in the present invention, which is the second requirement of the obviousness analysis. That is, even when combined, the three prior art references do not teach "...means to spectrally fan out an incoming light beam in a detection beam path of said confocal microscope..." and "...means to split said spectrally fanned out light beam out of a dispersion plane for said spectrally fanned out light beam ..."

Since Claims 40 and 43 depend from Claim 32 and the cited prior art neither suggests, nor contains all the elements recited in Claim 32, the Examiner is requested to withdraw the rejection.

Conclusion

Applicants respectfully submit that all pending claims are now in condition for allowance, which action is courteously requested.

Respectfully submitted,

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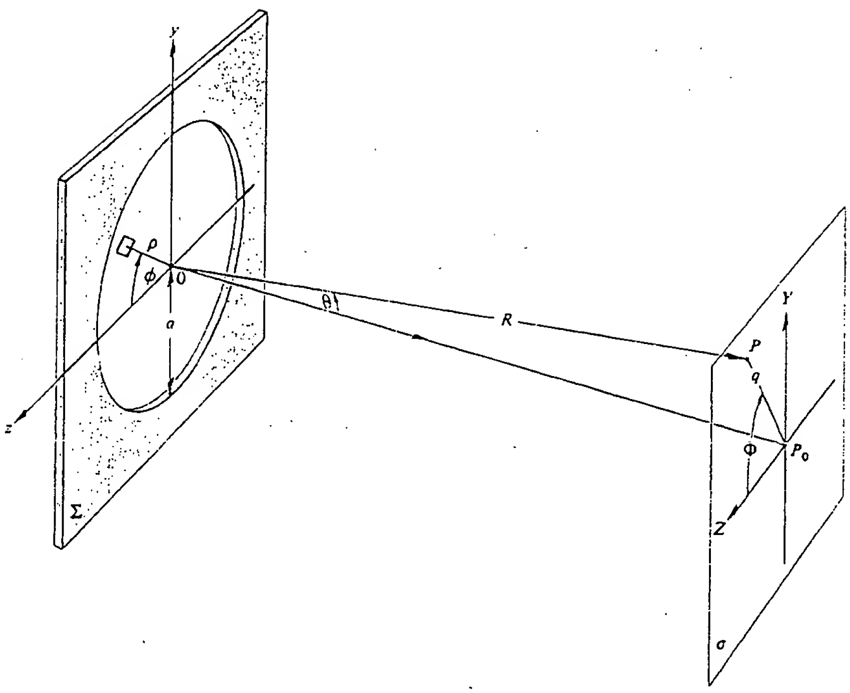


Fig. 10.26 Circular aperture geometry.

still smaller, e.g. the four corner peaks (whose coordinates correspond to appropriate combinations of $\beta' = \pm 3\pi/2$ and $\alpha' = \pm 3\pi/2$) nearest to the central maximum, each have relative irradiances of $(\frac{1}{22})^2$.

10.2.5 The Circular Aperture

Fraunhofer diffraction at a circular aperture is an effect of very great practical significance in the study of optical instrumentation. Envision a typical arrangement; plane waves impinging on a screen Σ containing a circular aperture and the consequent far-field diffraction pattern spread across a distant observing screen σ. By using a focusing lens L_2, σ can be brought in close to the aperture without changing the pattern. Now, if L_2 is positioned within and exactly fills the diffracting opening in Σ, the form of the pattern is essentially unaltered. The light wave reaching Σ is cropped so that only a circular segment propagates through L_2 to form an image in the focal plane. But quite obviously this is the same process that takes place in the eye, a telescope, microscope or camera lens. The image of a distant point source as formed by a perfectly aberration-free converging lens, is never a point, but rather some sort of diffraction pattern. We are essentially collecting only a fraction of the incident wavefront and cannot therefore hope to form a perfect image. As shown in the last section, the expression for the optical disturbance at P, arising from an arbitrary aperture in the far-field case, is

$$E = \frac{\mathcal{E}_A e^{i(\omega t - kR)}}{R} \iint_{\text{Aperture}} e^{ik(Yy + Zz)/R}\, dS. \qquad [10.41]$$

For a circular opening, symmetry would suggest introducing spherical polar coordinates in both the plane of the aperture and the plane of observation, as shown in Fig. 10.26. Therefore, let

$$z = \rho\cos\phi \qquad y = \rho\sin\phi$$

$$Z = q\cos\Phi \qquad Y = q\sin\Phi$$

and so the differential element of area is now

$$dS = \rho\, d\rho\, d\phi.$$

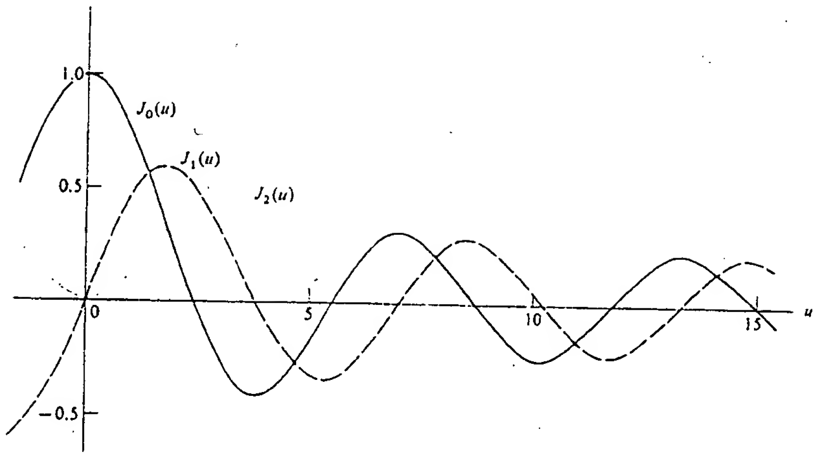


Fig. 10.27 Bessel functions.

Substituting these expressions into Eq. (10.41), it becomes

$$E = \frac{\mathcal{E}_A e^{i(\omega t - kR)}}{R} \int_{\rho=0}^{a} \int_{\phi=0}^{2\pi} e^{i(k\rho q/R)\cos(\phi-\Phi)} \rho \, d\rho \, d\phi \qquad (10.46)$$

Because of the complete axial symmetry, the solution must be independent of Φ. We might just as well solve Eq. (10.46) with $\Phi = 0$ as with any other value, thereby simplifying things slightly.

The portion of the double integral associated with the variable ϕ,

$$\int_0^{2\pi} e^{i(k\rho q/R)\cos\phi} \, d\phi,$$

is one that arises quite frequently in the mathematics of physics. It is a unique function in that it cannot be reduced to any of the more common forms, such as the various hyperbolic, exponential or trigonometric functions and indeed, with the exception of these, it is perhaps the most often encountered. The quantity

$$J_0(u) = \frac{1}{2\pi} \int_0^{2\pi} e^{iu\cos v} \, dv \qquad (10.47)$$

is known as the *Bessel function* (of the first kind) of order zero. More generally

$$J_m(u) = \frac{i^{-m}}{2\pi} \int_0^{2\pi} e^{i(mv + u\cos v)} \, dv \qquad (10.48)$$

represents the Bessel function of order m. Numerical values of $J_0(u)$ and $J_1(u)$ are tabulated for a large range of u in most mathematical handbooks. Just like sine and cosine, the Bessel functions have series expansions and are certainly no more esoteric than these familiar childhood acquaintances. As seen in Fig. 10.27, $J_0(u)$ and $J_1(u)$ are slowly decreasing oscillatory functions that do nothing particularly dramatic.

Equation (10.46) can be rewritten as

$$E = \frac{\mathcal{E}_A e^{i(\omega t - kR)}}{R} 2\pi \int_0^a J_0(k\rho q/R) \rho \, d\rho. \qquad (10.49)$$

Another general property of Bessel functions, referred to as a recurrence relation, is

$$\frac{d}{du}\left[u^m J_m(u)\right] = u^m J_{m-1}(u).$$

When $m = 1$, this clearly leads to

$$\int_0^u u' J_0(u') \, du' = u J_1(u) \qquad (10.50)$$

with u' just serving as a dummy variable. If we now return to the integral in Eq. (10.49) and change the variable such that $w = k\rho q/R$, then $d\rho = (R/kq)\, dw$ and

$$\int_{\rho=0}^{\rho=a} J_0(k\rho q/R) \rho \, d\rho = (R/kq)^2 \int_{w=0}^{w=kaq/R} J_0(w) w \, dw.$$

Making use of Eq. (10.50), we get

$$E(t) = \frac{\mathcal{E}_A e^{i(\omega t - kR)}}{R} 2\pi a^2 (R/kaq) J_1(kaq/R). \quad (10.51)$$

The irradiance at point P is $\langle(\mathrm{Re}\, E)^2\rangle$ or $\frac{1}{2}EE^*$, that is

$$I = \frac{2\mathcal{E}_A^2 A^2}{R^2}\left[\frac{J_1(kaq/R)}{kaq/R}\right]^2, \quad (10.52)$$

where A is the area of the circular opening. To find the irradiance at the center of the pattern, i.e. at P_0, set $q = 0$. It follows from the above recurrence relation ($m = 1$) that

$$J_0(u) = \frac{d}{du}J_1(u) + \frac{J_1(u)}{u}. \quad (10.53)$$

From Eq. (10.47) we see that $J_0(0) = 1$ and from Eq. (10.48), $J_1(0) = 0$. The ratio of $J_1(u)/u$ as u approaches zero has the same limit (L'Hôpital's rule) as the ratio of the separate derivatives of its numerator and denominator, namely $dJ_1(u)/du$ over one. But that means that the right-hand side of Eq. (10.53) is twice that limiting value, so that $J_1(u)/u = \frac{1}{2}$ at $u = 0$. The irradiance at P_0 is therefore

$$I(0) = \frac{\mathcal{E}_A^2 A^2}{2R^2}, \quad (10.54)$$

which is the same result obtained for the rectangular opening (10.43). If R can be presumed essentially constant over the pattern, we can write

$$I = I(0)\left[\frac{2J_1(kaq/R)}{kaq/R}\right]^2. \quad (10.55)$$

Since $\sin\theta = q/R$, the irradiance can be written as a function of θ:

$$I(\theta) = I(0)\left[\frac{2J_1(ka\sin\theta)}{ka\sin\theta}\right]^2, \quad (10.56)$$

and as such, is plotted in Fig. 10.28. Because of the axial symmetry, the towering central maximum corresponds to a high-irradiance circular spot known as the *Airy disk*. It was Sir George Biddell Airy (1801–92) Astronomer Royal of England, who first derived Eq. (10.56). The central disk is surrounded by a dark ring which corresponds to the first zero of the function $J_1(u)$. From the standard tables $J_1(u) = 0$ when $u = 3.83$ i.e. $kaq/R = 3.83$. The radius q_1 drawn to the center of this first dark ring can be thought of as the extent of the Airy disk. It is given by

$$q_1 = 1.22\frac{R\lambda}{2a}. \quad (10.57)$$

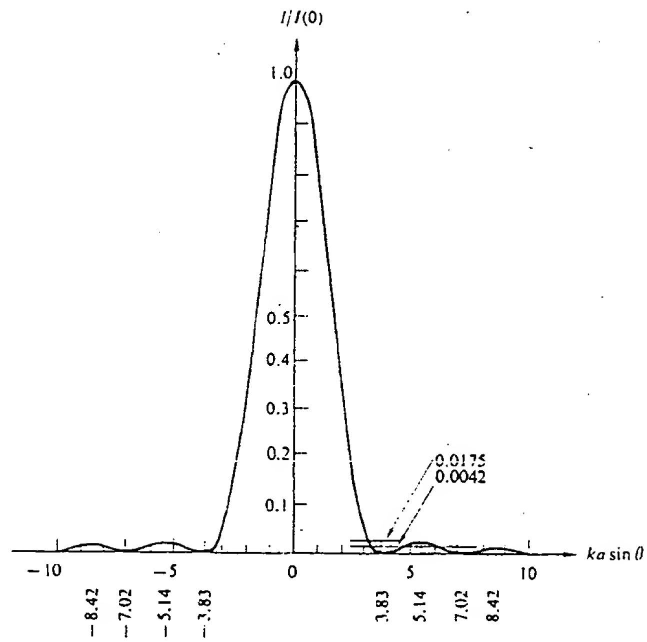


Fig. 10.28 The Airy pattern.

For a lens focused on the screen σ, the focal length $f \approx R$ and so

$$q_1 \approx 1.22\frac{f\lambda}{D}, \quad (10.58)$$

where D is the aperture diameter i.e. $D = 2a$. (The *diameter* of the Airy disk in the visible spectrum is *very roughly* equal to the $f/\#$ of the lens in millionths of a meter.) As shown in Figs. 10.29 to 10.31, q_1 varies inversely with the hole's diameter. As D approaches λ, the Airy disk can be very large indeed and the circular aperture begins to resemble a point source of spherical waves.

The higher-order zeroes occur at values of kaq/R equal to 7.02, 10.17, etc. The secondary maxima are located where u satisfies the condition

$$\frac{d}{du}\left[\frac{J_1(u)}{u}\right] = 0,$$

which is equivalent to $J_2(u) = 0$. From the tables then, these secondary peaks occur when kaq/R equals 5.14, 8.42, 11.6, etc.; whereupon $I/I(0)$ drops from one to 0.0175, 0.0042 and 0.0016 respectively.

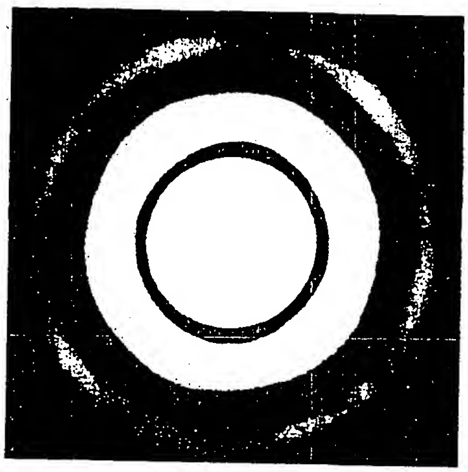


Fig. 10.29 Airy rings (0.5 mm hole diameter). [Photo by E.H.]

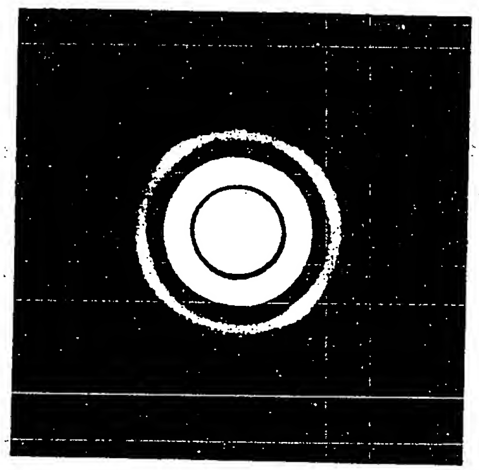
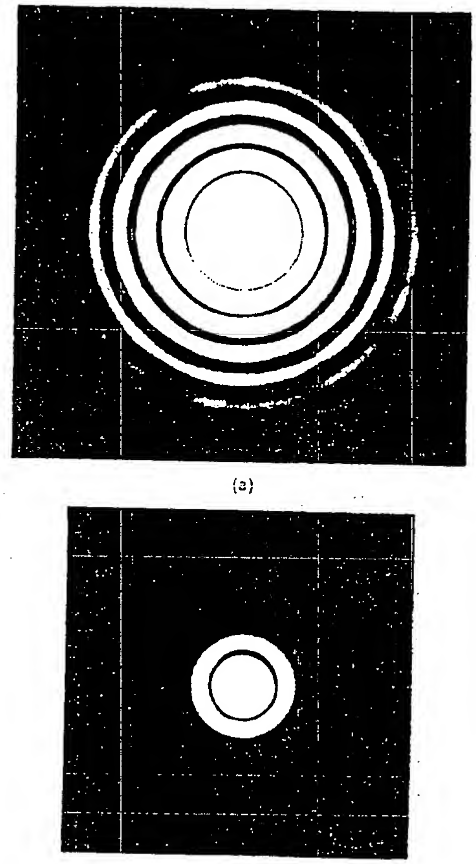


Fig. 10.30 Airy rings (1.0 mm hole diameter). [Photo by E.H.]



(a)

(b)

Fig. 10.31 (a) Airy rings—long exposure (1.5 mm hole diameter). (b) Central Airy disc—short exposure with the same aperture. [Photos by E.H.]

Circular apertures are preferable to rectangular ones as far as lens shapes go, since the circle's irradiance curve is broader around the central peak and drops off more rapidly thereafter. Exactly what fraction of the total light energy incident on σ is confined to within the various maxima is a question of interest, but one somewhat too involved to solve here.* On integrating the irradiance over a particular region of the pattern, one finds that 84% of the light arrives within the Airy disk and 91% within the bounds of the second dark ring.

10.2.6 Resolution of Imaging Systems

Imagine that we have some sort of lens system which forms an image of an extended object. If the object is self-luminous it is likely that we can regard it as made up of an array of incoherent sources. On the other hand an object seen in reflected light will surely display some phase correlation between its various scattering points. When the point sources

* See Born and Wolf, *Principles of Optics*, p. 398 or the very fine elementary text by Towne, *Wave Phenomena*, p. 464.